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BUREAU OF MINES
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FIREPROOFING MINE SHAFTS

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JOS. R. GUITERAS

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UNITED STATES DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

FIREPROOFING MINE SHAFTS[1]

By Jos. R. Guiteras[2]

The present discussion first presents data to justify the fireproofing of mine shafts. This is followed by a brief outline of fireproofing methods with examples from practice. A summary of authoritative recommendations on fire prevention concludes the discussion.

Acknowledgment is made to D. J. Parker, district engineer, Mine Safety Station, Salt Lake City, Utah, for his valuable criticism of the paper.

Fireproofing a mine shaft implies lining the shaft with fireproof material or rendering fireproof the materials already composing the shaft lining. A brief study of the part mine shafts and shaft stations have played in disastrous and tragic underground fires furnishes convincing evidence that every possible effort to make all mine shafts fireproof is amply justified. The fire hazard in coal mines obviously is much greater than in metal mines. In this discussion the point of view is mainly that of the metal miner; it is the opinion of the writer that all fires in metal mines are preventable.

Of 40 mine fires in the Lake Superior region[3] before 1917, 22 originated in shafts or shaft stations. In those days the candle was the main cause of underground fires. After candles had been replaced by carbide lamps and electric lights for illumination, and electric power had been applied more generally to underground use, mine fires continued to occur. Of the 50 fires in Lake Superior mines from 1917 to 1928, 22 were caused by electricity, as follows: 3 from main power circuits; 10 from trolley or lighting circuits; 3 from motor-feed circuits; 2 from signal circuits; and 4 from other electrical equipment. Sixteen of the 50 fires originated in shafts or stations, 10 in shafts, and 6 in shaft stations or pump stations. Of the 10 fires originating in shafts, 4 were caused by electricity, 2 from smoking, and 4 from overheated rollers in inclined timbered shafts. Of the 6 fires originating in stations, 3 were from electrical causes. The conclusions are inescapable that the adoption of electrical power for underground use introduced what has become a major fire hazard and that the mine shaft with its adjoining stations continued to be the most prominent starting point for underground fires, in the Lake Superior district, at least.

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[1] A discussion presented before the fourth conference of the Conservation Branch, Geological Survey, at Salt Lake City, Utah, Feb. 7, 1939.
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[2] Mining engineer, Metal-Mining Methods Section, Mining Division, Bureau of Mines, Salt Lake City, Utah.

[3] Gregory, F. C., Fires and Fire Prevention in Lake Superior Mines: Bureau of Mines Inf. Circ. 6073, 1928, 17 pp.

Turning to Montana experience, we find records of many underground fires in Butte in 1917. All but one originated from electrical installations. Contributory causes included: (1) Heavy continuous timbering, (2) strong ventilating pressures in shafts and airways, (3) subsidence and movement in the country rock, (4) corrosive action of mine water affecting electrical insulation, and (5) oxidation in old timbered stopes.

E. M. Norris has described the situation and the remedies applied.4/ The fire-prevention plan of the Anaconda Copper Mining Co. included (1) fireproofing, (2) improving electrical insulations, (3) extension of the underground water system, (4) better control of ventilating currents, and (5) increasing the efficiency of fire-fighting organizations.

In connection with the procedure followed by Anaconda and other mining companies in carrying out their fire-prevention programs, the following summary outlines the field of fireproof construction as applied to shaft linings. Standard applications5/ of fireproof construction include the use of (1) steel shaft sets, (2) precast reinforced concrete shaft sets, (3) concrete rings, (4) continuous concrete lining, and (5) gunite.

Steel Shaft Sets

Steel sets are of structural shapes. Wall plates, end plates, and dividers usually are H sections with the flanges vertical. Posts are made of angles. Guides usually are made of wood but sometimes are of steel; safety dogs on cages get a better grip on wooden guides. As much of the set as possible is shop-riveted; the rest is bolted in place. Steel sets sometimes are coated with gunite, poultry wire being used as reinforcement.

The Cary "A" shaft6/ at Hurley, Wis., is a five-compartment shaft using steel shaft sets with wooden blocking and 3-inch lagging. All surfaces were gunited 1-1/2 inches thick with 1 to 3 coats to fireproof the timber, to protect the steel from corrosion, and to waterproof the shaft. Triangular-mesh reinforcing wire was used on the timber, poultry wire on the steel.

4/ Norris, E. M., Underground Fire Prevention by the Anaconda Copper Mining Co.: Trans. Am. Inst. Min. Met. Eng., vol. 68, 1923, p. 77.

5/ Abstracted in part from Peele, Robert, Mining Engineers' Handbook, 1927.

6/ Young, G. J., The Application of Cement Mixtures by Machinery: Eng. and Min. Jour., vol. 111, 1921, p. 540.

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	Square feet
Wall surface covered..............................	14,261
Steel surface covered.............................	3,750
Total....................................	18,011

Materials Used

Sand......................................	cu. yd.	102.5
Cement....................................	bbls.	173
Reinforcing...............................	sq. ft.	14,261
Poultry wire..............................	do..	3,750

Linear feet of shaft = 263.13

Labor: 1 foreman and 6 men for 32 working days.

Cost: $9.30 per linear foot of shaft, or $0.136 per square foot of surface.

At the Homestake mine,[7] Lead, S. Dak., the Ellison hoist buildings were destroyed by fire. In sinking the new Ross shaft, it was therefore decided to use fireproof construction for the surface plant, the shaft for its full depth (5,000 feet), and the shaft stations.

Steel sets were selected, as steel was estimated to be cheaper than concrete. Wall plates and end plates are 6-inch H-beams weighing 25 pounds per foot; 14-gage galvanized corrugated-steel sheets, bolted in place, are used for lining the skip compartments. The only timber used is for guides and blocking. The cost of the steel sets is shown below:

	Cost per foot of shaft
Steel, invoice and unloading	$23.21
Steel, installing...........	12.73
Corrugated lacing, installed	8.04
Miscellaneous...............	6.34
Total..................	50.32

From the surface to a depth of 308 feet the shaft was concreted solidly outside of the sets at a cost of $13.46 per cubic yard, or $46.27 per foot of shaft concreted. Concrete was used also wherever the ground was bad; the rest of the wall surface was gunited. The total cost of the shaft for the 3,241.5 feet in which steel was used was $132.31 per foot including the cost of concreting and guniting the walls to the 2,450 level.

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[7] Bjorge, G. N., and others, Construction and Equipment of the Ross Shaft, Homestake Mining Co.: Trans. Am. Inst. Min. Met. Eng., vol. 126, 1937, p. 58.

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Precast Reinforced-Concrete Shaft Sets

Precast reinforced-concrete sets have members corresponding to those of timber sets, and have been used successfully in both vertical and inclined shafts.

The Oliver Iron Mining Co., Iron Mountain, Mich., used a 1:2:3 mixture in a vertical shaft; the Ahmeek Mining Co., Calumet, Mich., used a 1:3:5 mixture for plates and dividers and a 1:2:4 mixture for studdles in an 30° inclined shaft. At the Ahmeek shaft the cost of concrete sets at the shaft collar was only 60 percent of the cost of timber sets.

Concrete Rings

The ring method makes use of a monolithic concrete lining in horizontal bands separated by intervals of bare rock.

The City Deep Shaft, Rand, South Africa, used rings 18 inches high at 10-foot intervals, supplemented in heavy ground by continuous brick or concrete lining.

The United Verde shaft at Jerome, Ariz., 13 by 13 feet in the clear, was continuously lined with concrete (not less than 8 inches thick) for 1,550 feet, and was ringed for 450 feet below. Rings were 30 inches high on 6-foot centers. Costs were as follows:

Lining	Concrete mixture	Cost per cubic yard	Cost per foot of depth
Continuous	1:3:5	$53.80	$215.01
Rings.....	1:2:4	61.30	127.22

Saving by ring method, per foot of depth, $87.79.

Continuous Concrete Lining

This type of lining usually is poured to rock but sometimes is formed in the clear and anchored at intervals, in which case the intervening space may be back-filled. Concrete mixtures ordinarily used range from 1:2:4 to 1:3:6, and the thickness ranges from 8 to 18 inches.

The lining usually is placed from the bottom upward, but there may be several points of attack to keep the crew busy. Mixing usually is done at the surface, especially on large jobs; it sometimes is done underground. Skips, buckets, or pipes are employed to convey the concrete to the forms, which may be of wood or steel 2-1/2 to 12 feet high (average, 5 feet); the forms are greased for easy stripping. Steel forms are preferable for large jobs. Partitions with openings at intervals may be cast with the lining. Dividers of steel, timber, or precast concrete are common. Hitches are cored for them, or they rest on short steel beams embedded in the concrete. Reinforcement of lining usually consists of 1/2- or 3/4-inch bars, either round or square. The horizontal bars are spaced 6 to 9 inches apart; the vertical bars, about 24 inches apart.

Masonry linings, including concrete blocks, have been used in Europe, but concreting is preferred in the United States.

At the Frood mine[8] of the International Nickel Co. at Sudbury, Ontario, the No. 1 shaft is reinforced concrete. Shaft stations are reinforced concrete for 20 to 50 feet from the shaft, and can be closed off from the crosscuts by steel fire doors.

In the Chief Consolidated Shaft, Eureka, Utah, a lining 8 inches thich was formed in the clear for 1,950 feet, with a ring poured to rock every 10 feet, and a heavy bearer section deeply hitched every 100 feet.

Gunite

Gunite is a mixture of sand and cement applied wet under air pressure by means of a cement gun. It may be used to preserve steel or to preserve or fireproof timber. The material to be gunited is covered with wire mesh or expanded-steel lath. Mixtures range from 1 part of cement to 2-1/2 parts of sand to 1:5 at the gun. One bag of cement yields 32 square feet of a 1:4-1/2 mixture or 22 square feet of a 1:3 mixture, 1 inch thick. Sand should be minus-1/4 inch. The usual sizes of gun require 110 to 225 cubic feet of free air per minute at 40 to 75 pounds per square inch pressure.

The Portland Cement Association has published a booklet entitled "Concrete in Coal Mine Structures" and another entitled "Less Cost per Ton With Concrete." These describe in detail the use of concrete and gunite in mine shafts.

One of the first measures taken by the Anaconda Copper Mining Co.[9] in carrying out its fire-provention plan was to fireproof the Tramway No. 1 shaft by covering the timber sets and lagging with gunite. A 1/2-inch thickness of gunite was applied in two layers of 1/4 inch each. The surface of the timber was first cleaned by spraying with water. Twenty-seven-gage diamond-mesh metal lath, in pieces 24 by 96 inches, was nailed to the timber with sixpenny wire nails; 225 square feet were placed per man in 8 hours. Gunite was placed on 800 to 1,200 square feet per gun in 8 hours; two cement guns were used. Guniting 2,000 feet of four-compartment shaft, amounting to 175,465 square feet of surface, required 6,102 sacks of cement, 1,500 tons of sand, 165,495 square feet

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[8] Parker, R. D., Ventilation and Safety Practices at the Frood Mine of the International Nickel Co. of Canada, Limited: Trans. Am. Inst. Min. Met. Eng., vol. 109, 1934, p. 246.

[9] Norris, E. M., Fireproofing Mine Shafts of Anaconda Copper Mining Co.: Trans. Am. Inst. Min. Met. Eng., vol. 61, 1919, p. 201.

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of metal lath, and 2,600 pounds of nails and staples, and required 94 days time for a crew averaging 54 men including superintendence and surface labor. The requirements per square foot of lining were as follows: 5.2 pounds cement; 17.1 pounds sand; 0.015 pound nails and staples; 0.94 square foot metal lath; and 0.23 man-hour. The gunite was kept damp by sprinkling for several days. This procedure was shown by tests to prevent shelling off under intense heat.

On account of the satisfactory results from guniting the Tramway No. 1 shaft, the Anaconda Copper Mining Co. decided to gunite its other 24 main shafts in the Butte district. Timbers and lagging in shafts and stations were gunited. At intervals of 100 feet (above and below stations) the lagging was removed, and the gunite was carried back to the rock walls to prevent a fire from getting behind the timbering.

Gunite also was applied to all wooden structures near the mine shafts.

The following conclusions may be drawn from Anaconda's guniting experience:

1. Expanded metal lath is better than poultry wire for fitting on underground timber.

2. A thickness of 1/2 to 3/4 inch of gunite is enough for fireproofing.

3. A mixture of 3 parts of sand to 1 part of cement is best for guniting shaft timbers.

Evidence that mine operators are alert to the ever-present danger of electrical installations was voiced by C. D. Woodward,10/ as follows:

> Safety and avoidance of fire risks are the first requisites for underground electrical installations. Power cables should have an insulation factor for twice the normal operating voltage. In shafts and drifts, where subject to injury, cables should be armored with steel. If subject to the corrosive action of mine water, strands of steel armor should have a protective coating of lead. Supports for the cable in downcast shafts should be provided on every wall plate for 200 feet from the collar in order to support a possible ice load.

Gardner and Parker11/ described a fire in the No. 2 shaft of the Magma mine, Superior, Arizona, on November 24, 1927, as follows:

10/ Woodward, C. D., Electric Power for the Butte Mines: Eng. and Min. Jour., vol. 139, 1938, p. 32.

11/ Gardner, E. D., and Parker, D. J., Shaft Fires - Magma Mines: Bureau of Mines Rept. of Investigations 2882, 1928, 8 pp.

> The No. 2 shaft was timbered down to the 600 level; concreted from the 600 to the 1,200 level; gunited over timber from the 1,200 to the 1,600 level; then timbered to the bottom (2,700 feet). Guniting of the shaft sets had been discontinued below the 1,600 level because excessive decay had taken place in the gunited timber, and the gunite shell concealed the decay, thereby introducing the hazard of unexpected failure of the sets and possible wreckage of the cages.
>
> The fire started on the 2,250 station from an unknown cause and progressed up the shaft. The gunited section was burned out, but not so vigorously as the ungunited section below. The gunite acted as a definite fire retardant and reduced the caving of the ground that was supported by the gunited sets.

One of the observations made in connection with the fireproofing of this shaft was that the timber should have been treated with a preservative before being gunited.

Recommendations for fireproofing measures have been voiced from time to time by leaders in safety work, and there is a definite tendency toward fireproof construction. Equally strong recommendations and advice apply to the proper use and maintenance of fireproof structures and their accessories, and to safe practice generally in connection with recognized underground fire hazards. The following summary comprises some of the measures that have been recommended as a result of lessons that have been learned:

The safest surface construction is a steel headframe with a steel and concrete shaft collar to a depth of 25 feet.

Surface structures near a shaft should be of incombustible material or fireproofed and protected by a sprinkler system; otherwise, surface structures should be at least 100 feet from the shaft.

A steel door should be placed at the shaft collar.

All shafts, stations, landings, and shaft bottoms should be lined with fireproof material. It is more important to fireproof shaft bottoms and landings than the shaft itself. If a mine has a long life, concreting may not be an additional expense. Downcast shafts often are dry and should be lined with concrete. If shifting ground makes a concrete lining impractical, the timbered shaft should be fireproofed with gunite. At intervals of 100 feet, gunite should be extended to the rock walls to prevent a fire from creeping in the timber behind the gunite. Where gunite cannot be used, water sprays controlled from the surface should be provided, or automatic sprinklers may be employed. Dry timbered shafts should be sprinkled at intervals to keep them damp. Even if timbers are gunited it is advisable to use a sprinkler system.

There should always be a water main large enough to supply several streams of water near the shaft and timbered workings. In this connection, the air line should be available for conversion to an extra water-supply line, and equipped with valves for sprinkling.

There should be a break in the continuity of timbering between pump stations and a shaft, by using steel sets, if necessary, to hold the ground.

Power lines are preferably brought underground through a drill hole.

A few more general precautions include the following:

Trolley wires and electric light bulbs should not come in contact with timbers.

Oil and grease as well as explosives should be stored in a fireproof place away from shaft stations and timbered workings. Dynamite and blasting caps should not be stored in the same place.

Every mine should have a controlled ventilating system with fire doors to isolate the levels from the shaft. An underground telephone system should be provided with telephones at shaft and pump stations.

Inflammable rubbish should not be allowed to accumulate.

For mines with much timbering, there should be a fire-inspection system and the men should be trained in fire prevention and in the use of fire-fighting equipment.